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BIOCHEMICAL FUEL CELLS

REPORT NO. 3 THIRD QUARTERLY REPORT

1 NOVEMBER 1963 THROUGH 31 JANUARY 1964

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NATIONAL AERONAUTICS and SPACE ADMINISTRATION
WASHINGTON, D.C.

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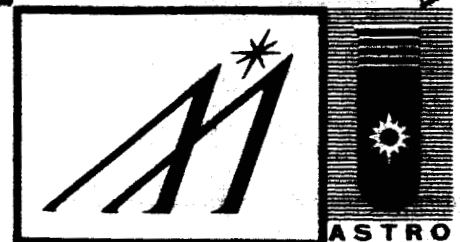
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February 28, 1964
Ref: 295/885-21/3518

National Aeronautics & Space Administration
400 Maryland Avenue S.W.
Washington 25, D.C.

Attention: Dr. Michael Del Duca (Code RB)

Subject: Study of Biochemical Fuel Cells
under Contract No. NASw-654

Enclosure: (1) Third Quarterly Engineering Progress Report,
"Study of Biochemical Fuel Cells," Report
No. 25,124 dated 28 February 1964

1. Enclosure (1) describing the technical results of the work accomplished to date on this program is hereby submitted, in accordance with Article IV, Section B, of the subject contract.

THE MARQUARDT CORPORATION

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Capt. 075 cover

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* Third Quarterly Progress Report,

1 November 1963 through 31 January 1964

STUDY OF BIOCHEMICAL FUEL CELLS *

(NASA Contract NASw-654)

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ABSTRACT

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The purpose of the investigations described in this report was to continue empirical studies on biochemical fuel cells for degrading human wastes and producing electrical energy therefrom. Specifically, the study includes the attachment of organisms to electrode materials, electrode pretreatment and configuration, the selection of suitable organisms and separator materials, selection of electrolytes and additives, structural materials and control devices, and storage and performance characteristics.

During the Third Quarter, investigations were continued to determine the effect of the feces:urine ratio upon the electrochemical characteristics of the biochemical fuel cell. It was concluded that the feces:urine ratio has a relatively minor effect over the range from 10 to 40 grams of feces per 100 milliliters of urine.

Chemical-electrochemical reactions were separated from biochemical fuel cell reactions by isolating the microorganisms from the anode by means of a cellulose acetate membrane, but products formed by the metabolic reactions could diffuse through the membrane to the anode. The data showed that the electrochemical power output of the cell increased with time, over the 170 hours of the experiment, apparently because of the formation of electrochemically active metabolic products which diffused to the anode.

Current continuously withdrawn from the cell has been maintained at a constant value by means of a galvanostat, and thus far a total current of 47.6 coulombs of electricity has been withdrawn from a cell containing approximately 80 milliliters of a fuel-anolyte mixture prepared at a concentration of 30 grams non-sterile, human feces per 100 milliliters of non-sterile, human urine. This total current did not represent the maximum that could be obtained, but the electrical power output had become so low that continuation of the experiment was not practical. The potential varied during this experiment, but was maintained very low in order to draw as much current as possible; therefore, the watt-hours of power withdrawn during this experiment was negligible.

Specific microorganisms (Proteus mirabilis and Escherichia coli) were added to non-sterile feces-urine mixtures, but without noticeable effect upon the open-circuit potential of the system.

Author

Experiments were also conducted in which the chemical-biochemical reactions were separated from the electrochemical reactions. This was accomplished by pumping the fuel-anolyte mixture through the cell and returned to a reservoir, so that the time of contact of the fuel-anolyte with the electrodes was only a small percentage of the total time the material was in the system. These data were compared with those of a non-flow system, in which the fuel-anolyte was not isolated from the electrode. There was no definite correlation between the systems on either a total time or cell time basis. Further work will be done to relate the ratio of electrode surface:fuel-anolyte volume to the time.

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STUDY OF BIOCHEMICAL FUEL CELLS

I. INTRODUCTION

This report covers the progress attained during the Third Quarter, 1 November 1963 through 31 January 1964, in the Study of Biochemical Fuel Cells, Contract No. NASw-654. The purpose of this program is to conduct empirical studies on biochemical fuel cells for producing electrical energy through degradation of human waste.

II. REPRODUCIBILITY

The reproducibility of the data obtained from the biochemical fuel cells is determined at frequent intervals, as described in previous reports (see Section X of the First Quarterly Report and Section IV of the Second Quarterly Report). These tests are not time-consuming and last approximately 24 hours. They provide valuable information in verifying that the system is the same and invariant with time, and in eliminating questions regarding the effects of possible contamination and of changes in sources of materials or in techniques that may occur over an extended period of time.

The reproducibility of the flow system was determined under the following conditions:

1. Flowing System

Cell: Plastic (Lucite)

Electrodes: Platinized screen (90% - 10% Rh), 80 mesh, 0.003 in. diameter wire, 2-1/8 in. clear diameter, 3.54 sq. in. geometric area.

Separator: Cellulose acetate (Sargent S-14825, 0.001 in. thick).

O-Rings: Silicone (Dow Corning S-7180).

Catholyte: 5 wt. % NaCl - 5% KCl in sterile, deionized water; non-biological; bubbled with purified, gaseous oxygen.

Waterproof and Chemically Resistant Paint: Temprotec TP220 Red (Ryan Herco Products Corp., Burbank, California).

Fuel-Anolyte: 30 grams nonsterile, human feces (frozen and thawed) in 100 ml. nonsterile, human urine (either fresh, or frozen and reheated to 120°F to redissolve the precipitated salts). Feces was obtained from volunteers on a low-cellulose diet, and was frozen immediately after collection. The mixture was homogenized with a Waring Blendor Deluxe (Waring Products Corp., New York City). Bubbled with helium during experiment.

The anolyte and catholyte reservoirs are common to two cells in parallel.

The statistical data are presented in Table I.

Polarization and power data were obtained during one of the standard reproducibility experiments (Experiment 42), and the data obtained are summarized in Table II. A general description of the method employed in obtaining polarization and power data is presented in Section III.

The reproducibility of the nonflow system has also been determined periodically during this program. The experimental conditions are described below:

2. Nonflow System

Cell: Glass, H-shape, O-ring type

Electrodes: Platinized platinum foil, 1 sq. in. area (non-opposing faces coated with waterproof and chemically resistant paint).

Separator, O-Rings, Catholyte, Fuel-Anolyte, and Waterproof and Chemically Resistant Paint: Same as for flowing system.

In one experiment conducted during the third quarter, three nonflow cells were assembled and the statistical results obtained are presented in Table I.

The data obtained during the reproducibility studies show that a satisfactory level of reproducibility was attained with the flow system in Experiments 41 and 42. The data obtained in Experiments 39 and 40, with the flow and non-flow systems, respectively, were not satisfactory; the reason was not determined, and this fact re-emphasizes the need for reproducibility experiments.

III. POLARIZATION AND POWER CURVES

Additional polarization and power data have been obtained during the Third Quarter, under a variety of conditions as described in the pertinent sections of this report. The polarization and power data obtained from these experiments are summarized in Table II.

The apparatus used in obtaining these data was described in Section VIII of the First Quarterly Report.

Briefly, the method involves automatically plotting voltage vs. current of a cell by placing a motor-driven variable resistance in the external circuit of the cell. The resistance varies from a maximum of 200,000 ohms to short circuit over a period of approximately 6 hours. Power curves are obtained by cross-plotting the data of the polarization curves.

IV. EFFECT OF FECES-URINE RATIO

An experiment was conducted to verify previous results obtained in determining the effects of feces-urine ratio on the electrochemical characteristics of the biofuel cell. The results of this experiment (No. 43) are presented in Table II. The cells are identified as follows:

<u>Cell Number</u>	<u>Gms. Feces/100 ml. Urine</u>
I	10
II	20
III	30
IV	40

It may be concluded on the basis of these data that the feces-urine ratio has a relatively minor effect upon the electrochemical characteristics of the biochemical fuel cell, over the range from 10 to 40 grams of feces per 100 milliliters of urine.

V. SEPARATION OF CHEMICAL-ELECTROCHEMICAL FROM BIOCHEMICAL FUEL CELL REACTIONS

A series of experiments is being conducted to separate the chemical and biochemical reactions in a biofuel cell. The experimental three-arm H-cell employed in these experiments is shown in Figure 3. The conditions of the experiment (electrodes, O-rings, catholyte, and waterproof paint) were the same as those shown in Section II, except for using the three-arm H-cell instead of the conventional two-arm H-cell (see Figure 4, Second Quarterly Report). In this application, the center arm is the sterile anode chamber, one of the outer arms is the cathode chamber, and the other outer arm is the biological (non-sterile), electrodeless chamber. The procedure was modified by sterilizing a portion of fuel-anolyte (by autoclaving) and putting it into the anode chamber; in this chamber only electrochemical reactions can occur. A portion of nonsterile fuel-anolyte was placed in the biological, electrodeless chamber, where only biochemical reactions can occur.

The anode chamber was separated from both the cathode and biochemical chambers by inserting cellulose acetate membranes at the O-ring joints.

A conventional two-arm H-cell was used as a control in this experiment. The conditions for this cell again were the same as those listed in Section II, except that the fuel-anolyte was a portion of the sterilized fuel-anolyte prepared for the anode chamber of the three-arm cell. In this manner, any strictly chemical-electrochemical reactions occurring in the fuel-anolyte of the anode chamber of the three-arm cell would be duplicated in the two-arm cell, and the effects could be separated from those of other types of reactions occurring in the three-arm cell. The other type of reaction occurring in the three-arm cell would involve the transport of electrochemically active molecules formed in the biological chamber, through the cellulose acetate membrane, to the anode chamber. Therefore, this experiment shows whether electrochemically active products are formed as a result of metabolism of the indigenous microorganisms in human waste.

The results of the experiment are summarized in Table II. The cells are identified as follows:

I = Two-Arm Cell; II = Three-Arm Cell

The anodic open-circuit potential of the three-arm cell seemed to be slightly better than that of the two-arm cell during the first 76 hours of the experiment, but during the next 60 hours there was no

definite difference in the potentials of the two cells. The attainment of only slight differences of potentials was considered to be due possibly to limited diffusion through the cellulose acetate membrane.

The experiment was repeated, but the separator between the biological outer chamber and the anode inner chamber was a 0.45 micron Millipore filter paper, instead of the cellulose acetate used previously. The Millipore filter paper was chosen because its pore size is sufficiently small to prevent diffusion of microorganisms to the anode chamber, but large enough to permit rather free diffusion of any electrochemically active molecules formed in the biological chamber.

Again, the anodic open-circuit potential of the three-arm cell was slightly better than that of the two-arm cell, by perhaps 0.1 volt, for the period from 17 hours to 75 hours, even though the open-circuit potential of the three-arm cell was originally approximately 0.225 volt less than that of the two-arm cell (the two cells should have been almost duplicates at the beginning of the experiment). Over the period from 85 hours to 140 hours, the open-circuit potentials of the two cells did not differ significantly.

Two polarization tests were made with the three-chamber H-cell, and the results are presented in Table II (see Experiment 46). The polarization tests were reasonably separated in time, and it appears that electrochemically active compounds were formed by metabolic activity, and that these compounds then diffused to the anode and caused an increase in anodic power density over that obtained initially through purely chemical reactions.

The experimental method was modified by placing a second anode in the biological chamber of the three-arm H-cell; in all other respects, the experiment was the same as that described above. The purpose of this experiment was to determine the difference in electrochemical behavior between a biological and a nonbiological anode, with provision for interdiffusion. It was found that the open-circuit anodic potential obtained from the nonsterile (outer) anode was greater than that obtained from the sterile anode for the first 50 hours. After that time, the open-circuit potential obtained from the sterile anode was approximately 200 millivolts greater than that obtained from the nonsterile anode (referenced to saturated calomel).

The data indicate that although the nonsterile system produced a better potential originally, the chemicals present in that system apparently became depleted rather rapidly, while those of the sterile system did not.

No polarization or power data were obtained from this experiment, because the longer electrolytic path between the cathode and biological anode, the presence of the nonbiological anode between the cathode and the biological anode, and the addition of the Millipore filter between the biological and nonbiological anodes, increased the internal resistance of the cathode-biological anode circuit above that of the cathode-nonbiological anode circuit.

VI. CONTROL OF CURRENT WITHDRAWAL BY GALVANOSTAT

A galvanostat-potentiostat, constructed in this laboratory, was used in one experiment to continuously control the current withdrawn from a biofuel cell at a constant value. The purpose of the experiment was to determine the effect of current withdrawal upon the electrochemical properties of a biofuel cell and to determine the total amount of electrochemical energy obtainable from human waste.

The experiment was conducted in the flow system, under the conditions described in Section II. This system was chosen because of its better electrochemical configuration, in comparison to that of the non-flow system.

After 32 hours, there was no noticeable effect of current withdrawal (at a rate of 1 milliamperes) on the anodic potential. The current of 1 milliamperes represents a current density of approximately 40 milliamperes per square foot.

The experiment was then conducted in the non-flow system described in Section II. A current of 18 to 34 microamperes was withdrawn from the system, after periodically resetting the galvanostat; this represents a current density of 2.6 to 4.9 milliamperes per square foot. Control of current withdrawal with the galvanostat was maintained within 1 microampere. Over a period of ten days, a total of 4.29 coulombs was withdrawn from the cell. The open-circuit anodic potential improved with time, from an initial value of -0.43 volt to -0.66 volt (referenced to saturated calomel), though the portions of the change caused by time alone (i.e., metabolic) and that due to electrochemical reactions resulting from current withdrawal could not be separated, since both occur simultaneously in the non-flow system.

The withdrawal of only 4.29 coulombs of current was not limited by the fuel cell reactions; the experiment could have been continued, but a polarization run was made on this system after the 4.29 coulombs of current had been withdrawn, and the electrical power output was extremely

poor. The data are summarized in Table II (Experiment 47), where it is seen that the peak anodic power density was only 0.2 milliwatts per square foot and the short circuit current density only 4 milliamperes per square foot at that time.

VII. ADDITION OF SPECIFIC MICROORGANISMS

Although the majority of the investigations are being conducted with indigenous microorganisms, a limited amount of study is being devoted to the determination of the effects caused by adding selected microorganisms to feces-urine mixtures.

In one experiment, conducted in the flow system under the conditions described in Section II, 1 percent by volume of a culture of Proteus mirabilis (grown in nutrient broth) was added to the fuel-anolyte after the potential had become stable. The reason for choosing Proteus mirabilis for this system was that it is a prolific producer of hydrogen sulfide, and the primary goal of this type of experimentation, using pure strains of microorganisms, is to establish biochemical-electrochemical reaction mechanisms, in an applied sense. Proteus mirabilis is aerobic, facultatively anaerobic, and is indigenous to human fecal matter.

The addition of Proteus mirabilis to non-sterile human waste after a period of stabilization of the anodic open-circuit potential (47 hours) produced no noticeable effect. This result may have been caused by the fact that the material utilizable by P. mirabilis may have been depleted by indigenous microorganisms and no longer available when the culture of P. mirabilis was added.

In another experiment, conducted as above, 1 percent by volume of a culture of Escherichia coli was added instead of the P. mirabilis. The addition of E. coli was made after the anodic open-circuit potential has become stabilized (48 hours), and again there was no noticeable effect on the anodic potential. The same explanation may apply as in the case of the P. mirabilis.

VIII. SEPARATION OF CHEMICAL-BIOCHEMICAL FROM ELECTROCHEMICAL FUEL CELL REACTIONS

Some experiments have been conducted to determine the extent of electrochemical reactions in the biofuel cell, which occur in the proximity of the electrode, in contrast to purely chemical-biochemical reactions, which are independent of the electrodes.

The method employed was to run flow and non-flow systems simultaneously under the conditions described in Section II, and compare the variation in electrochemical properties with time. In the non-flow system, the total volume of fuel-anolyte mixture (approximately 80 milliliters) is confined near the electrode (see Figures 4 of the First or Second Quarterly Reports), whereas in the flow system only a small portion of the fuel-anolyte is actually in the fuel cell at a given time and the remainder is in the reservoir (see Figure 7 of the First Quarterly Report, or Figure 2 of the Second Quarterly Report). The ratio of total time:cell time provides an indication of the ratio of the amount of time the fuel-anolyte is in the fuel cell and can contact the electrode for electrochemical reactions, to the total amount of time the mixture is in the system. For diffusion, it is recognized that the distance of fuel-anolyte from the electrode is greater in the non-flow system than in the flow system (considering only fuel-anolyte mixture actually in the biofuel cell); there is a maximum of approximately 2 inches in the former and $\frac{1}{2}$ inch in the latter. However, because of the agitation provided in the non-flow system by bubbling helium into the mixture, the diffusion rates are probably high enough that they are not the limiting steps in the reaction. The ratio of total time:cell time is assumed, therefore, to be 1.0 in the non-flow system, and varies with the ratio of total volume of fuel-anolyte in the flow system to the volume of fuel-anolyte contained in the fuel cell (approximately 31 milliliters).

In the first experiment, the ratio of total volume:cell volume was 9.0. No current was drawn during this experiment, except for the minor amount withdrawn by the voltmeter (10^6 ohms input impedance) for 3 seconds each half-hour.

The purpose of this experiment, the first in the series, was to establish reproducibility of the two systems. It was noted that the open-circuit potential of the non-flow system employing a platinized platinum foil anode was approximately 100 millivolts greater than that of the flow system employing a platinized screen of 90% platinum - 10% rhodium.

In a second experiment, the ratio of the total volume of anolyte in the flow system to the volume of anolyte in the biofuel cell was 12.2. Experimental conditions were the same as those described above, except that the current was maintained constant at a given time by means of the galvanostat, and varied during the experiment from 20 to 34 microamperes. The flow and non-flow cells were connected in series to the galvanostat, so that the same current was drawn from both cells. The current densities were in the range from 2.88 to 4.89 and from 0.81 to 1.38 milliamperes per square foot, for the non-flow and flow systems, respectively.

The data were plotted for the flow system on both a cell time and total time basis. There was no direct relationship between the anodic open-circuit potentials of the two systems as a function of time, on either basis.

Further work will be done to relate the ratio of electrode surface:fuel-anolyte volume to the time.

In a slightly different approach toward separating chemical-biochemical reactions from electrochemical reactions, two non-flow cells were assembled under the conditions described in Section II. Current was withdrawn from one cell, maintained at a constant rate by means of the galvanostat, while the other cell was a control from which only infinitesimal amounts of current were withdrawn; i.e., only the small current that flowed through the voltmeter (10^6 ohm input impedance) during the 3-second voltage reading each half-hour during the test. The current withdrawn from the cell varied from 20 to 62 microamperes (2.88 to 8.94 milliamperes per square foot) and a total of 47.5 coulombs were withdrawn during the experiment.

The data are presented in Table II (see Experiment 55), and indicate that the withdrawal of the current caused the electrical power output to be decreased significantly, from a peak anodic power density of 1.75 milliwatts per square foot of electrode surface after 30 coulombs of electricity had been withdrawn from the cell (total elapsed time 146 hours), to 0.2 milliwatts per square foot after 47.6 coulombs had been withdrawn (total elapsed time 339 hours). This decrease in power was not caused by time alone, since the control cell (essentially no current withdrawn) gave a peak anodic power density of 2.1 milliwatts per square foot after 382 hours total elapsed time. The withdrawal of 47.6 coulombs of electricity did not represent the maximum that could be obtained, but the experiment was terminated when it seemed to be impractical to continue because of the low power level obtainable at that time.

IX. PRETREATMENT OF HUMAN WASTE

One of the objectives of this program has been to pretreat the human waste to either (a) increase the rate of degradation of the waste, (b) change the products formed, or (c) improve the electrochemical characteristics of the biofuel cell.

The conditions of this type of experiment have been essentially the same as those described for the nonflow system in Section II, except that after preparing and homogenizing the fuel-anolytes mixture,

it is sterilized by autoclaving at 250°F for 20 minutes. Then a culture of some selected microorganism is added, usually to the extent of about 1 percent by volume of culture in the sterile fuel-anolyte mixture.

These experiments are run in pairs, one being maintained at 95-100°F and the other a control at room temperature (75°F).

The first experiment was run to determine the effects of temperature alone as a pretreatment. Indigenous microorganisms were used; i.e., the fuel-anolyte was not sterilized for this experiment. The results are presented in Table II.

The data indicate that when indigenous microorganisms are used, better electrochemical characteristics are obtained if the system is maintained at room temperature than if it is incubated at 95-100°F.

X. MISCELLANEOUS

A bomb calorimeter is being used to determine the heating value of feces, as a measure of its energy content. Some calibration runs were made with the calorimeter and some feces were dried in preparation for actual experiments at which time an insulator cracked and pressure could no longer be maintained in the bomb. A new insulator has been ordered.

The gas chromatograph that will be used in the chemical analyses of human waste products has undergone a major overhaul, and is being calibrated.

The digital voltmeter was extremely erratic at one time during this quarter and has also undergone a major overhaul.

XI. FUTURE WORK

During the next quarter, experiments will be conducted in the following general areas:

- A. Determination of the effect of bubbling gases in producing several concurrent effects, such as by increasing chemical-biochemical reaction rates, decreasing polarization, and removing gaseous products which may be either inhibitory or favorable reactants.
- B. Chromatographic and polarographic analyses of feces-urine mixtures and their products.
- C. Measurement of gas production rates by means of manometric apparatus.
- D. Continuation of literature reviews on sewage treatment and measurement of biological oxygen demand.
- E. Periodic reproducibility studies will continue to be made.
- F. Limited studies in the use of specific enzymes or micro-organisms to promote specific reactions in human waste.
- G. Use of pure fuels (ethyl alcohol, ammonia, hydrogen, hydrogen sulfide, methane) under the conditions employed with biofuel cells.
- H. Concluding bomb calorimetric studies.

XII. BIBLIOGRAPHY

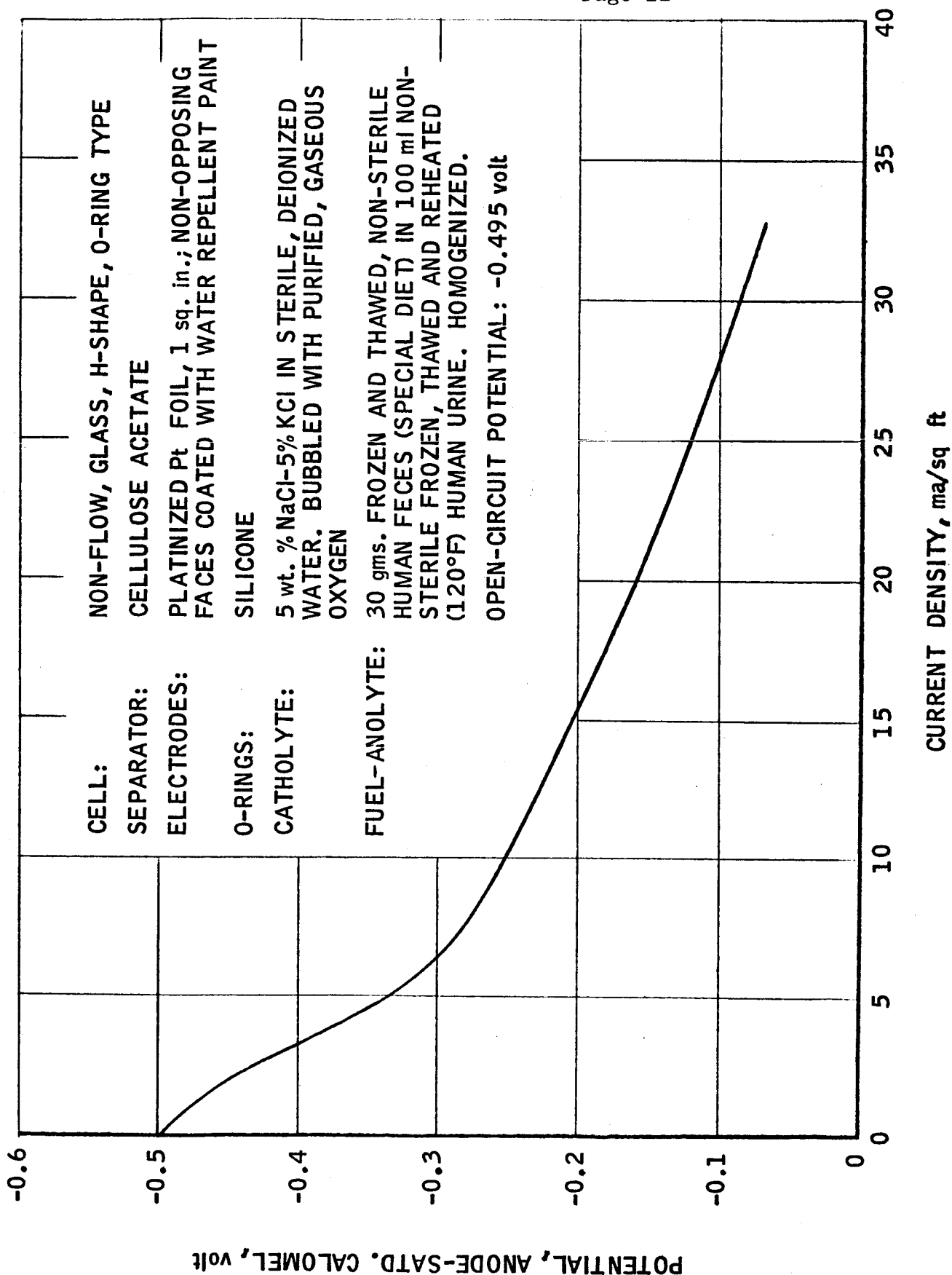
Breed, R.S., E.G.D.Murray, and N.R.Smith, Bergey's Manual of Determinative Bacteriology, Williams & Wilkins Co., Baltimore (1957).

Rosebury, T., Micro-organisms Indigenous to Man, McGraw-Hill Book Co., Inc., New York (1962).

APPENDIX

DATA AND APPARATUS

ANODIC POLARIZATION



ANODIC POWER DENSITY

CELL: NON-FLOW, GLASS, H-SHAPE, O-RING TYPE
 SEPARATOR: CELLULOSE ACETATE
 ELECTRODES: PLATINIZED Pt FOIL, 1 sq. in.; NON-OPPOSING
 FACES COATED WITH WATER REPELLENT PAINT
 O-RINGS: SILICONE
 CATHOLYTE: 5 wt. % NaCl-5% KCl IN STERILE, DEIONIZED
 WATER. BUBBLED WITH PURIFIED, GASEOUS
 OXYGEN
 FUEL-ANOLYTE: 30 gms. FROZEN AND THAWED, NON-STERILE
 HUMAN FECES (SPECIAL DIET) IN 100 ml NON-
 STERILE FROZEN, THAWED AND REHEATED (120°F)
 HUMAN URINE. HOMOGENIZED.

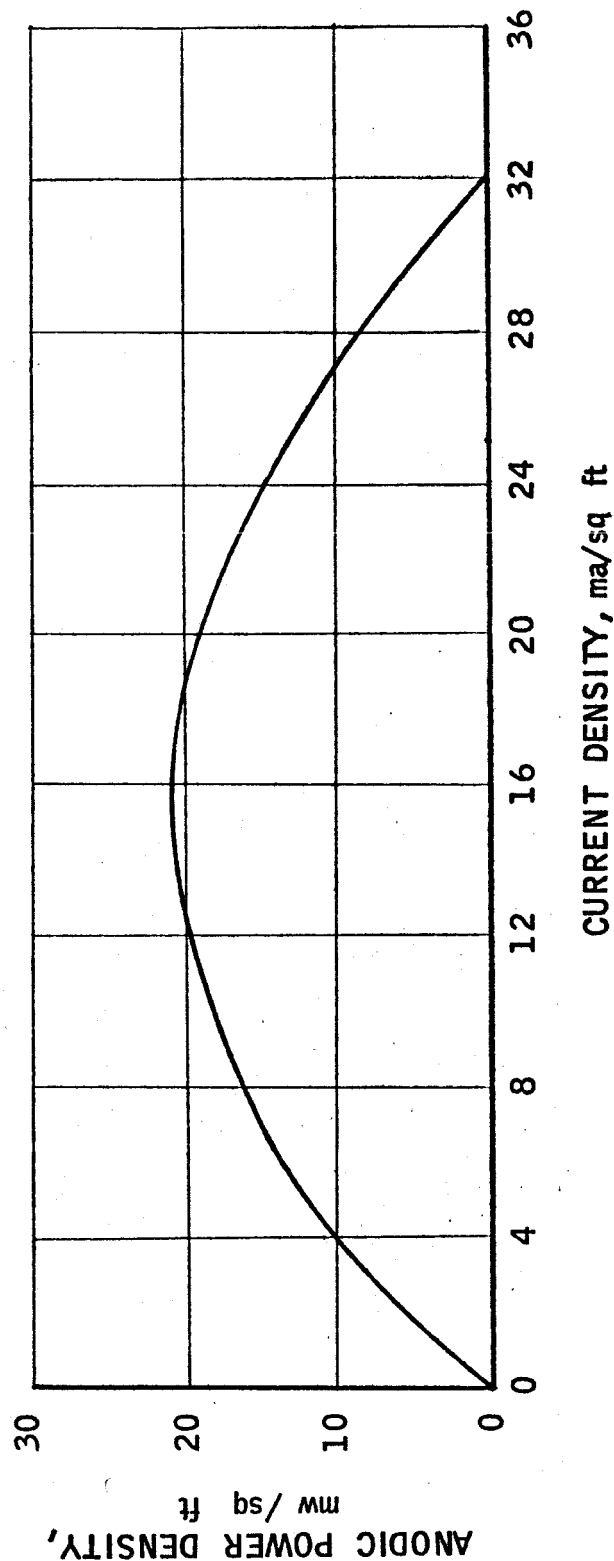


FIGURE 2

THREE-ARM H-CELL

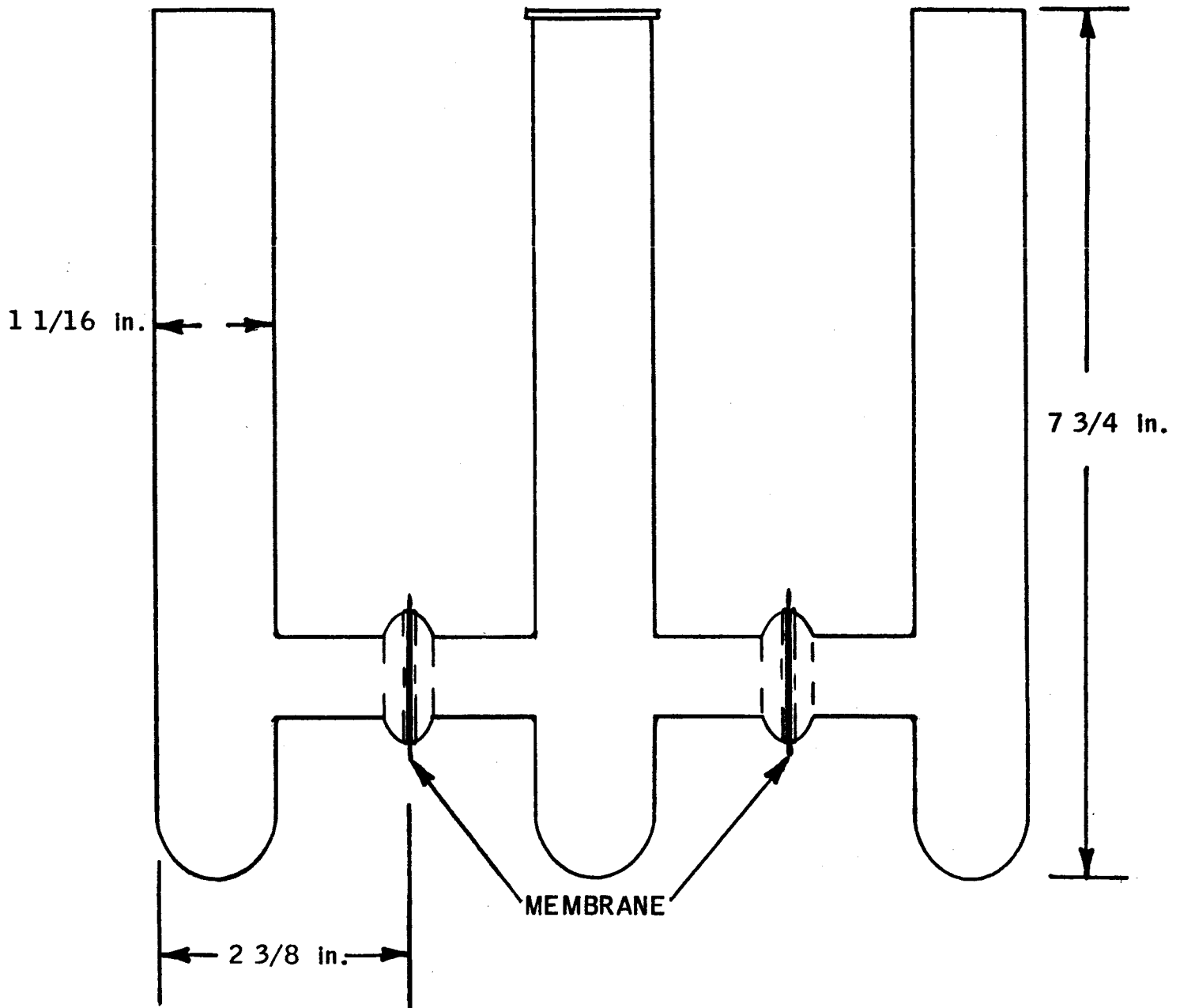


TABLE I

STATISTICAL DATA FROM REPRODUCIBILITY TESTS

Experiment No.	39	40	41	42
Type of System	Flow	Non-flow	Flow	Flow
No. of Cells	2	3	2	2
Mean of Maximum Differences of Potentials (millivolts)	113.6	114.0	19.5	27.5
Mean Deviation	51.1	21.4	10.6	35.2
Variance	3706	1024	155	3391.6
Standard Deviation	60.9	32.0	12.4	58.2

TABLE II

POLARIZATION AND POWER DATA

Run No.	42	43-I	43-II	43-III	43-IV	44-I	44-II
Described in Section	II	IV	IV	IV	IV		
Peak Anodic Power Density (mw./sq. ft.)	1.45	1.42	1.22	1.42	1.68		
Peak Total Power Density (mw./sq. ft.)	2.0	1.65	1.42	1.58	1.95		
Short Circuit Current Density (ma./sq. ft.)	40	18	20	24	22	4	3
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.520	-0.533	-0.494	-0.523	-0.540	-0.265	-0.326
Best Anodic Open-Circuit Potential (volt)	-0.600	-0.540	-0.536	-0.685	-0.659	-0.695	-0.585
pH, Initial	7.5	7.3	7.7	8.0	8.2	7.8 ⁽¹⁾	8.2 ⁽²⁾
pH, Final	8.6	8.7	8.8	8.9	8.8	8.8	8.7 ⁽¹⁾ 8.5 ⁽²⁾
Duration of Test (hours)	116		138			169	
Elapsed Time of Test Prior to this Polarization Run (hours)	27	48	42	25	21	50	42

(1) Non-sterile fuel-anolyte

(2) Sterile fuel-anolyte

TABLE II (Continued)

POLARIZATION AND DATA

Run No.	46(1)	46(2)	47
Described in Section			IV
Peak Anodic Power Density (mw./sq. ft.)	0.72	2.2	0.2
Peak Total Power Density (mw./sq. ft.)	0.84	3.25	0.2
Short Circuit Current Density (ma./sq.ft.)	15	50	4
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.570	-0.600	-0.509
Best Anodic Open-Circuit Potential (volt)	-0.700		-0.665
pH, Initial	7.5(3)		8.0
	8.0(4)		
pH, Final	-		-
Duration of Test (hours)	213		374

- (1) After 76 hours
- (2) After 170 hours
- (3) Sterile arm
- (4) Non-sterile arm

TABLE II (Continued)

POLARIZATION AND DATA

Run No.	51		
Temperature (°F)	75	95-100	95-100
Peak Anodic Power Density (mw./sq. ft.)	2.1	1.6	0.6
Peak Total Power Density (mw./sq. ft.)	2.45	1.9	0.75
Short Circuit Current Density (ma./sq. ft.)	32	33	17
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.495	-0.545	-0.542
Best Anodic Open-Circuit Potential (volt)	-0.812	-0.683	
pH, Initial	8.3	8.3	
pH, Final	8.97	8.8	
Duration of Test (hours)		400	
(Hours Completed at Start of Test)	385	170	363

TABLE II (Continued)
POLARIZATION AND DATA

Run No.	55	55	55
Peak Anodic Power Density (mw./sq. ft.)	1.75	0.2	2.1
Peak Total Power Density (mw./sq. ft.)	2.15	0.25	2.45
Short Circuit Current Density (ma./sq. ft.)	30	6	32
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.575	-0.514	-0.745
Best Anodic Open-Circuit Potential (volt)	-0.760		-0.810
pH, Initial		8.3	
pH, Final		8.7	9.0
Duration of Test (hours)		408	
Total Current withdrawn prior to this experiment (coulombs)	30	47.6	0
Elapsed Time at Start of This Test (Hours)	146	339	382

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